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Tracer Test Design and Sensitivity Studies of the Cove Fort Geothermal Resource Tracer Test

K. K. Bloomfield
Idaho National Engineering and Environmental Laboratory

J. N. Moore and M. C. Adams
Energy and Geoscience Institute

T. L. Sperry
Bud L. Bonnett Geothermal Plant

Abstract

The Cove Fort-Sulphurdale geothermal system produces both dry steam from a shallow parasitic vapor cap and liquid from an underlying liquid-dominated resource, offering a unique opportunity to analyze reservoir and tracer behavior. To aid our design of a tracer test we constructed a preliminary numerical model for the Cove Fort-Sulphurdale reservoir. Liquid and vapor-phase tracers were injected into the reservoir in January 1999. Steam containing the refrigerant R-134a, used to trace the movement of the vapor phase, was observed in the production wells after 2 weeks. As of December 2000, tracer concentrations were still increasing but appeared to be leveling off. Cumulative tracer returns suggest that the steam cap taps a small fraction of the injectate plume near the injection well. Fluorescein was used to trace the liquid injected. To date, no fluorescein has been observed in samples from the well that discharges liquid water. Calibration of the numerical model to match the tracer return curves suggest that recharge relates to deep circulation of ground waters.

Introduction

Numerical models assist management of complex geothermal resources and save resource and development dollars. Numerical models are most widely used to estimate energy extraction for a given reservoir management scheme and to optimize overall reservoir operations. Where few reservoir parameters are known, simulation is also useful in identifying parameters that have a large effect on operating conditions. Numerical modeling of gas and liquid tracers has been motivated by their widespread use in geothermal reservoir testing and management

Tracer tests help monitor fluid movement and reveal information on areal coverage of water injection. Design of a tracer test is typically improved by using a numerical model (Rose et al. 1997), which offers more accurate estimates of transport times and tracer concentrations and improves the cost efficiency of tracer tests.

Gas tracers are highly volatile and sparingly soluble. They are injected as vapor. Examples of gas tracers are noble gases and refrigerants. Liquid tracers have low or moderate volatility and may be injected as liquids. Examples include tritiated water and salt solutions (e.g., flouresein). Ideal liquid tracers exhibit phase partitioning behavior similar to the geothermal water. Both gas and liquid tracer behavior can be estimated with numerical models.

The Geothermal Field

The Cove Fort-Sulphurdale geothermal resource is operated by the Utah Municipal Power Agency. The Bud L. Bonnet Geothermal Plant produces 6 to 7 MW of electricity. The resource is near the intersection of Interstates 15 and 70 in Beaver and Millard Counties, Utah. Unocal proved the existence of this moderate-temperature resource when they drilled Well 42-7 in 1977, but they abandoned the project due to low reservoir pressure, costly drilling, and size of the resource. Mother Earth Industries discovered a vapor-dominated steam cap during drilling of Federal Well 34-7 (Linda) in October 1983, and production from the steam cap has continued since 1985. The steam cap is presently produced by five wells. A hot-water well, P91-4, was placed into production in June 1996. The spent fluid produced from P91-4 is injected into well 42-7. Spent fluid was traced with flouresein and the gas tracer R-134a. The connectivity between injection well 42-7, the steam zone, and well P91-4 can be estimated by numerical simulation and confirmed by tracer testing.

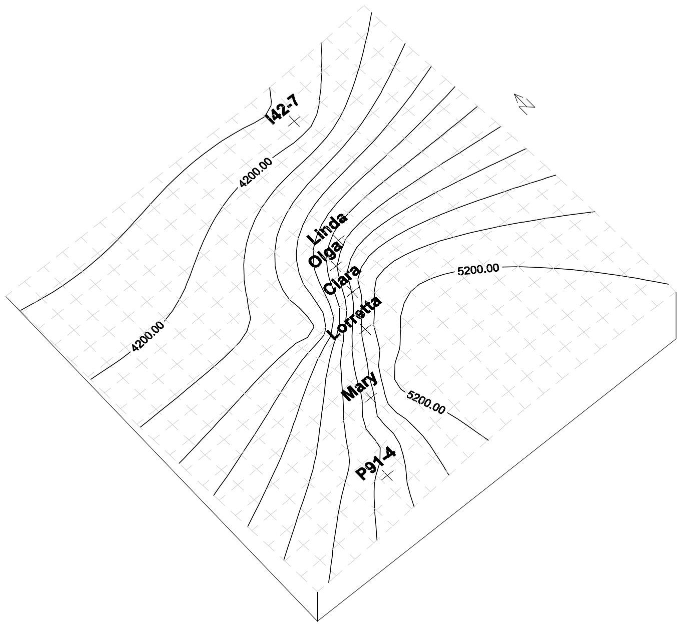

Figure 1. Reservoir top and well locations**.**

Figure 1 shows the locations of the production and injection wells imposed on what is believed to be the top of the reservoir. There are currently six production wells. Five of the wells discharge dry steam from Coconino sandstone. The depth to the top of the sandstone and the top of the steam cap decreases systematically from north to south. The deepest dry steam wells (Olga and Linda) produce steam from depths of 1,112 to 1,152 feet. These wells had initial temperatures of 296 to 303^{o}F. Mary, located at the southern end of the field, produces steam from 839 to 869 feet. The sandstone appears to have a thickness of about 200 feet.

P91-4 produces water from the underlying liquid resource. This well was drilled to 2,444 feet. P91-4 encountered steam at 846 feet, the water table at 1,030 feet. It has a maximum temperature of 305^{o}F. The water table appears to be near the top of the limestone, immediately below the sandstone. Liquid water is presently produced at 305^{o}F. The water is flashed through a high-pressure separator operated at 36 psia, and the remaining water is routed through a low-pressure separator at atmospheric pressure. The high-pressure separator is operated at the same header pressure as the steam wells. High-pressure steam is then routed to a condensing turbine. Low-pressure steam is routed to binary units. The remaining water is injected into well 42-7, where it enters the reservoir at the base of the volcanic section between depths of 1,930 and 2,350 feet at a temperature of 214^{o}F. This water is the sole injectate.

Well 42-7 was originally drilled to 2,358 feet and recorded a maximum temperature of 350^{o}F near the base of the well. To date, this is the highest temperature recorded in the field. The full lateral and vertical extent of the vapor-dominated cap has not yet been defined by drilling.

Modeling Approach

The Cove Fort Sulphurdale numerical model is three-dimensional. The areal size of the model is 7,000 by 7,000 feet. The data available for the model included well surface locations, elevation, depth to top of reservoir, and monthly power generation data. We gave the reservoir a uniform thickness of 400 feet, using the estimated thickness of the Coconino Sandstone, underlying limestone, and depth of the injector, which are the producing formations of the geothermal liquids. The study area was modeled areally by a 20 by 20 grid. The vertical grid was five layers of varying thickness.

Cove Fort-Sulphurdale resource boundaries are not well defined. We believe that the model covers an area large enough for the boundary temperatures given by the normal temperature gradient and for pressures to be hydrostatic. For the initial pass at modeling the area, we used no-flow boundaries on all sides of the domain. Later simulation exploiting the resource indicated we need more mass and energy to match the production history. We initially believed there was a regional mass flow from the Tushar Mountains, east of the reservoir, and that the heat source was associated with the Woodtick Volcano to the west. To simulate the mass flow, we attached recharge and discharge zones on the east and west sides of the model.

Rock properties for the numerical simulation were those of typical sandstone. Permeability was estimated from the steady-state radial flow of incompressible fluid, using production rate and drawdown pressure from the hot-water well. The calculated permeability was 10 darcies and was assumed constant field wide. We assumed porosity to be a constant 5%, based on drill cuttings and fractures of the Coconino Sandstone.

Saturations were initialized to develop a 200-ft-thick steam zone with an underlying liquid-dominated zone. A heat flux of 50 mW/m^2 was added to the bottom of the model, and heat was lost through the top of the model to develop a vertical temperature gradient. The model was then initialized for 100 years to develop a stable steam cap and appropriate temperature gradient in the underlying liquid dominated zone.

The simulation model uses three material components: the native fluids, another component of water to represent the fluorescein tracer, and the gas tracer (R-134a). The phase behavior and solubility of most hydrofluorocarbons have not been measured at temperatures above 212^{o}F. For this numerical simulation study, we extrapolated low-temperature phase behavior to higher temperatures.

Sensitivity Studies

Parameters found to be important vary from study to study, depending on the nature of the reservoir, the recovery process of interest, and the study objectives or questions. When tracer data became available, we performed sensitivity studies on the preliminary tracer test design model. The studies determined what reservoir description data were important, that is, what reservoir parameters were significant in attempting to match the observed tracer test. Parameters tested were injection temperature, porosity, and the geometry or location of recharge and discharge of the model domain. When matching the tracer test returns, it became apparent that the location of recharge and discharge was the most sensitive parameter.

As indicated in our original model, to aid in the design and sampling frequency we used the scenario of recharge from the east and discharge to the west of the model. We then created different scenarios, where recharge and discharge were moved geometrically around the model from north to south, northeast to southwest, and interior to the model. In each scenario, we history matched the pressure and flow of the production wells. History matching was to adjust the pressures of the recharge and discharge aquifers. Figures 2 through 4 illustrate the simulated and observed tracer test, showing the geometry of recharge and discharge of the geothermal fluids. The scenario that best matched the tracer test was with the recharge in an area east of the producers Olga and Linda and discharge to the west.

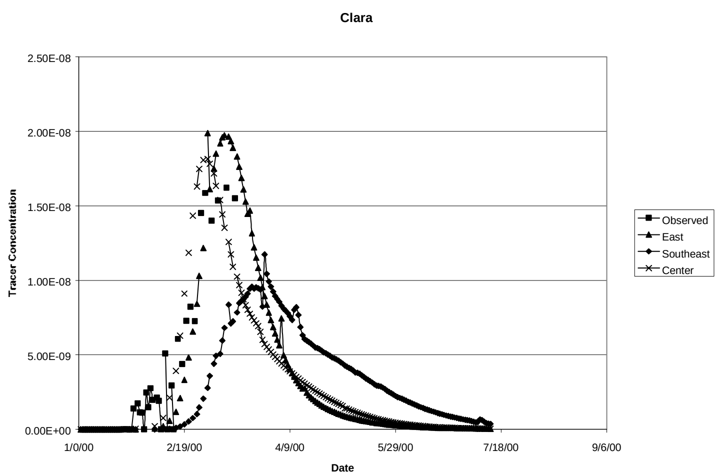

Figure 2. Clara steam well, simulated and observed tracer test.

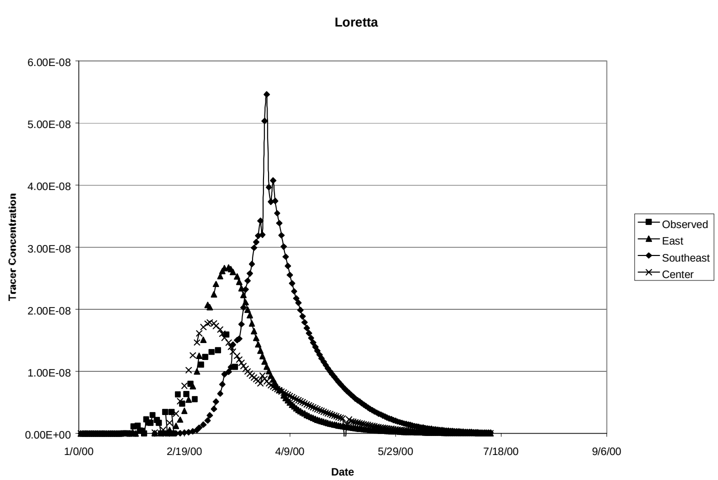

Figure 3. Loretta steam well, simulated and observed tracer test.

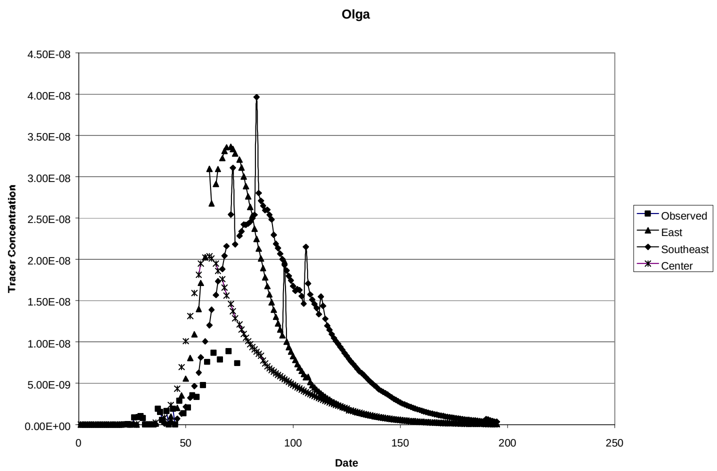

Figure 4. Olga steam well, simulated and observed tracer test.

The significance of our numerical simulation results can be validated. During the drilling of the geothermal wells no overlying aquifers were encountered, even though cold springs discharge to the east and perched aquifers have been found to the west of the field. Cove Fort-Sulphurdale geothermal resource appears to be related to deep circulation of ground waters because of the $^{3}He/^{4}He$ ratios of the geothermal fluids show no evidence of a magmatic component that would be present if the system was influenced by the Woodtick volcano (Tonani et al 1998). Out crops of Tetiary quartz monzonite and related dikes occur on the flank of the Tushar Mountains, and compositionally similar dikes and metamorphosed limestone have been encountered in the deepest of the wells (42-7). Geophysical data suggests that these outcrops are part of a larger intrusive complex centered under the productive portion of the Cove Fort Sulphurdale resource (Ross and Moore, 1985). To the west, within the Cove Fort Sulfurdale graben, alluvial and Cenozoic basalt flows overlie older rocks. Integrating tracer testing, geological, geochemical data, improves the usefulness of numerical simulation.

Conclusion

Investigations of the Cove Fort-Sulphurdale geothermal system are providing a unique opportunity to analyze reservoir and tracer behavior in a moderate-temperature field producing dry steam from a parasitic vapor cap and liquid water from the underlying liquid reservoir. A tracer test was conducted in January, 1999, to evaluate the movement of steam and liquid and the effects of injection. Liquid (fluorescein) and vapor-phase (R-134a) tracers were injected at a depth below the producing horizons. R-134a was detected in all of the steam wells two weeks after injection. Concentrations of R-134a at Cove Fort-Sulphurdale have progressively increased during the last 10 months. Less than 1% of the R-134a and no fluorescein has been recovered to date. These results suggest that the early tracer returns have come from a location where the reservoir taps a small fraction of the slowly moving, liquid injection flow close to the injection well.

Acknowledgments

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